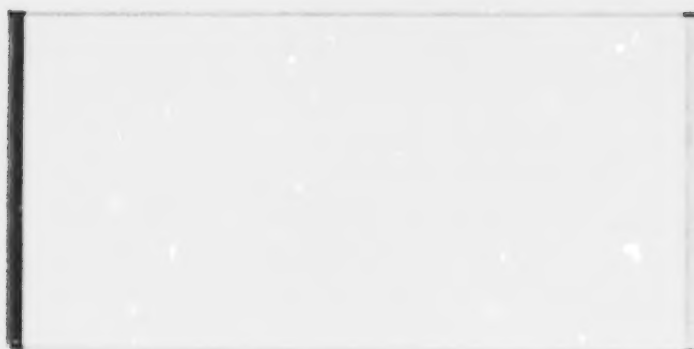
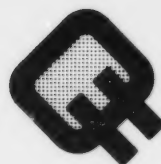


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**MEASUREMENT AND ANALYSIS
OF AIR LEAKAGE THROUGH A BLOCK WALL**

Report No. 86-284-K

I.G. Elphick
J.H. Russell

Mechanical Testing & Development Section
Mechanical Research Department

ABSTRACT

This report describes the measurement and analysis of air leakage for the Bruce GS-A instrument room block wall. The purpose of the test was to determine the wall leakage and wall flow resistance as a function of wall pressure. The wall test facility included an enclosure on one side of the wall in which air could be pressurized. The pressure in the enclosure and the air mass flowrate into the enclosure (and hence through the wall) were measured for a range of wall pressures. Testing proceeded until the wall pressure was sufficient to crack the wall. The measured data was used to calculate the wall flow resistance. This was then used to calculate the pressure history in the instrument room from a given pressure history in the turbine hall.

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EXECUTIVE SUMMARY

MEASUREMENT AND ANALYSIS OF AIR LEAKAGE THROUGH A BLOCK WALL

I.G. Elphick, J.H. Russell
Mechanical Testing and Development Section
Mechanical Research Department

The instrument rooms within the turbine hall of a CANDU nuclear power station must protect electronic equipment used for the control and monitoring of station processes. The instrument room walls must have sufficient strength to resist overpressures in the turbine hall and they must be impermeable to the extent that water vapour from the turbine hall, in the event of a steam line break, would not damage the electronics. To test the strength and permeability of the Bruce GS-A instrument room block wall, a test facility was constructed by Bruce NPD - Construction. The instrumentation required to determine the wall leakage, and hence its permeability, was supplied by Research Division. This report focuses on the measurement of the block wall leakage and the calculation of the wall flow resistance.

The block wall test facility included a 12' x 24' (3.7m x 7.3m) sample block wall with a 7.5" (19.05cm) deep enclosure, four air compressors, and associated instrumentation. The compressors supplied air to the wall enclosure through 3" (7.62cm) hoses, thereby allowing a constant pressure to be maintained on one side of the block wall. The flowrate of air to the wall enclosure, and hence through the block wall was measured with an orifice flow meter. The wall enclosure was well sealed to ensure that all air entering the wall enclosure could escape only through the block wall. A microcomputer was used to monitor and record wall pressure and flowrate.

The test procedure included pressurizing the wall enclosure to a steady value and then recording 1/ the pressure in the wall enclosure and 2/ the air flowrate to the wall enclosure. Four sets of data were recorded, represented by wall pressures of 0.15, 0.25, 0.4 and 0.5 psig (102.3, 103.0, 104.1, 104.8 kPa). The data was stored on floppy disk for later analysis.

The results of the test are represented as plots of wall leakage and wall flow resistance versus wall pressure. It was observed during testing that the block wall developed cracks at a wall pressure of 0.4 psig. The wall leakage for the uncracked wall is 30 and 45 cfm (51, 76 m³/hr) for the wall pressures 0.15 and 0.25 psig, respectively. A wall flow resistance was calculated

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calculated given the wall mass flowrate and the wall pressure drop. The average wall flow resistance is 6.9×10^9 and 7.7×10^9 for the wall pressures 0.15 and 0.25 psig, respectively. Knowing the wall flow resistance, a pressure history in the instrument room was calculated given a pressure history in the turbine hall. The turbine hall pressure histories represented the pressures at a ruptured steam main line for a 20% and 100% break. The results of the simulation show that the maximum pressure drop across the instrument room wall is approximately equal to the maximum overpressure in the turbine hall.



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To Mr. B.R. Churchill
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Design & Constr, H18 A2

MEASUREMENT AND ANALYSIS OF AIR LEAKAGE THROUGH A BLOCK WALL

1.0 INTRODUCTION

Within the turbine hall of a CANDU nuclear station are one or more instrument rooms which house electronic equipment used for controlling and monitoring in the station. It is important that this equipment is well protected to ensure the proper functioning of all station processes and safety systems. The walls of the instrument room provide a pressure and moisture barrier. Therefore, it is important that these walls can withstand any pressures which may occur in the turbine hall and that any leakage of moisture or contaminants through the walls will not affect the operation of the instruments.

The strength and permeability of the instrument room walls can be determined experimentally by constructing a test facility which includes a section of the wall. The strength of the wall may be determined by applying a pressure to one side of the wall and increasing the pressure until the wall fails. The permeability of the wall may be determined by measuring the flowrate of air passing through the wall as a function of the pressure behind the wall. A wall flow resistance may be calculated given the wall pressure and the wall leakage.

This report describes the facility and test procedure for the sample block wall and the analysis of the test results.

2.0 ESTIMATE OF FLOWRATE AND WALL
RESISTANCE ON 10' x 10' BLOCK WALL

The instrumentation for the wall test facility includes a flow meter to measure the wall leakage and a pressure tap to measure the wall pressure. Figure 1 shows the location of the instrumentation on a side view of the wall test facility. An enclosed air space is created on one side of the wall using C-channels and steel plate. Air leakage between the enclosure and the wall was prevented by caulking the joints. The pressure tap is fastened to one of the plates. A flow meter is installed in the air line leading to the air space.

To size the flow meter and the pressure transducer, it was necessary to estimate the wall pressure and the wall leakage. The estimated pressure for failure of the wall was given to be 1 psig (108.2 kPa)/1/. To estimate the maximum flowrate, it was required to know the wall flow resistance. Data from a pressure test on a 10' x 10' (3.1 m x 3.1 m) block wall were used. Details of the calculation are shown in Appendix A. The wall flow resistance ranged from 227×10^6 to 553×10^6 . Since the wall for that test was filled with grout and was coated with an asphalt emulsion, it was expected that the loss coefficient for the standard block wall would be much less. Therefore a loss coefficient of 100×10^6 was chosen. The dimensions of the wall were 12' x 24' (3.7 m x 7.3 m). Given a wall pressure of 1 psig, the estimated mass flowrate was 0.235 lbm/s (0.107 kg/s) which is a volume flowrate of 180 cfm ($306 \text{ m}^3/\text{hr}$).

An orifice plate was selected for the flow measurement of air into the wall enclosure. It was sized to measure flowrates in the range of 100 to 2000 cfm (170, $3400 \text{ m}^3/\text{hr}$) and was installed into an 8" Schedule 40 pipe. Given that four compressors were available, each capable of delivering 600 cfm ($1020 \text{ m}^3/\text{hr}$), the flow meter was capable of measuring any flowrate produced.

3.0 EXPERIMENTAL DETERMINATION OF FLOWRATE AND WALL RESISTANCE ON 12' x 24' BLOCK WALL

3.1 OBJECTIVES

Data collection for this study proceeded in parallel with the tests being performed by Bruce NPD - Construction. The test facility which included the block wall and frame (Figure 2) and the compressors (Figure 3) were supplied by Bruce Construction. The orifice meter, pressure transducers (Figure 4) and data acquisition equipment (Figure 5) were supplied by Research Division. To determine if the wall flow resistance varied with pressure, the wall leakage was to be measured at five wall pressures. It was recommended that the wall pressure be held constant for five minutes each at 0.20, 0.40, 0.60, 0.80 & 1.00 psig (102.7, 104.1, 105.4, 106.8, 108.2 kPa) while the air flowrate was monitored.

3.2 EQUIPMENT

3.2.1 Air Circuit

The air circuit consisted of four 600 CFM ($1020 \text{ m}^3/\text{hr}$) air compressors, a flow metering and control spool piece and the wall enclosure. See Figure 6 for a schematic. The four air compressors were connected in parallel to the input header at the upstream end of the spool piece with 3" (7.62 cm) diameter flexible hose (Figure 7). Downstream of the header was a gate valve used to control the flowrate of air and hence the pressure behind the wall. Following the valve was 10 diameters of 8" SCH 40 pipe (7.981" or 20.27 cm dia), an orifice plate mounted between flanges and another 5 diameters of pipe. The orifice diameter was 2.4053" (6.1095 cm) and the orifice pressures were taken from flange taps. At the downstream end of the spool piece was another header. Four hoses connected the header to the wall enclosure (Figure 8).

3.2.2 Data Collection

The instrumentation used for data collection included a single-ended pressure transducer connected to the upstream flange tap, a differential pressure transducer connected to both flange taps and a single-ended pressure transducer connected to a pressure tap mounted on the wall enclosure. The wall pressure was monitored with a manometer connected to the wall enclosure.

When steady state flow conditions were reached (as indicated by a constant pressure at the wall enclosure) the three pressure transducers were scanned 50 times at equal time intervals for 3 minutes. A microcomputer collected the data through an analogue-to-digital converter and stored it on floppy disk.

3.3 TEST PROCEDURE

The test procedure consisted of pressurizing the wall enclosure to a steady value and recording the pressures for 3 minutes. Steady state flow was achieved by manually opening the gate valve and noting the wall pressure as indicated by the manometer. When the wall pressure settled to the desired value, data collection was initiated. Four sets of data were collected at wall pressures of 0.15, 0.25, 0.4 and 0.5 psig (102.3, 103.0, 104.1, 104.8 kPa).

One compressor was sufficient to pressurize the wall enclosure to 0.4 psig. At this pressure cracks were first noticed in the wall. Above 0.4 psig, the cracks opened and it was difficult to maintain a constant wall enclosure pressure.

3.4 RESULTS

The data stored on floppy disk was used to calculate the wall leakage and flow resistance. The two pressures measured at the orifice plate were used to calculate the wall leakage. The wall flow resistance was calculated from the wall pressure and the wall leakage. Appendix B shows the detailed calculations of the data reduction. The reduced data are shown in Table 1.

Figure 9 shows the wall leakage plotted as a function of wall pressure for the four sets of data. At a wall pressure of 102.3 kPa (0.15 psig), the mass flowrate of air through the wall was averaged at 0.016 kg/s (30 cfm). The wall leakage increased to 0.022 kg/s (40 cfm) when the wall pressure was increased to 103.0 kPa (0.25 psig). At a wall pressure of 104.1 kPa (0.4 psig), the wall leakage increased by a greater amount and it was observed that small cracks were forming in the wall. Very large cracks were observed in the wall when the wall pressure was increased to 104.7 kPa (0.5 psig) and the wall leakage increased substantially (Figure 10).

Figure 11 shows the wall flow resistance plotted as a function of the wall pressure for the four sets of data. For the lower wall pressures, 102.3 and 103.0 kPa (0.15, 0.25 psig), the average wall flow resistance was 6.9×10^9 and 7.7×10^9 . The wall flow resistance decreased at the higher wall pressures due to the cracks in the wall.

4.0 NUMERICAL MODELLING OF PRESSURE HISTORIES

From a structural viewpoint, it is important that the pressure drop across the instrument room wall does not exceed the design limits. Given a pressure history at the break point of a steam line in the turbine hall, the pressure history in the instrument room can be calculated using the wall flow resistance as determined above. A flow resistance of 7.3×10^9 was chosen for the following calculations because it is the average value for the block wall before cracking occurred (see Table 1). The instrument room dimensions are 19' x 12' x 29' (5.8 m x 3.7 m x 8.8 m). The four vertical walls are constructed from concrete block and the floor and ceiling include steel plate. Therefore, the permeable surface area used in the calculation was that of the four vertical walls. Appendix C shows the details of the calculation procedure.

Two turbine hall pressure histories were used as input data for this simulation. These include the overpressures in the turbine hall at a ruptured steam main line for a 20% and 100% break/2/. It was assumed that the pressure at the exterior side of the instrument room was equal to the break node pressure. Figure 12 shows the pressure histories for the case of 100% SM. The overpressure in the instrument room increased to 0.1 kPa (0.015 psi) after 60 seconds. Figure 13 shows the pressure histories for the case of 20% SM. The overpressure in the instrument room continued to rise even at 60 seconds. It would level off at 0.03 kPa (0.0044 psi), if the turbine hall pressure remained constant. Both plots show that the maximum pressure drop across the instrument room wall is approximately equal to the maximum overpressure in the turbine hall. This is so because the transient time of the turbine hall pressure histories was much shorter than the response time of the instrument room.

5.0 CONCLUSIONS

The Bruce GS-A block wall test facility has been used to determine the leakage rate and flow resistance for pressures up to that which caused cracking.

The major observations and conclusions are as follows:

1. The wall leakage, before cracking occurred, was 0.022 kg/s (40 cfm) at a wall pressure of 103.0 kPa (0.25 psig).
2. The average wall flow resistance, before cracking occurred had a value of 7.3×10^9 .
3. The block wall was observed to crack at a wall pressure of 104.1 kPa (0.4 psig).

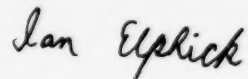
4. For the conditions being considered, the maximum pressure drop across the instrument room wall is approximately equal to the maximum overpressure in the turbine hall.

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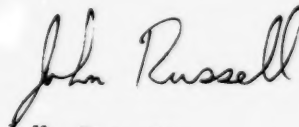


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REFERENCES

1. Verbal communication with George Chan, Bruce Engineering.
2. Bruce GS-A, Powerhouse Environment Study Report, D&D Report No. 85360.

Table 1: BRUCE BLOCK WALL LEAKAGE TEST - REDUCED DATA

WALL PRESSURE [kPa]	WALL LEAKAGE [kg/s]	WALL FLOW RESISTANCE	LOG RESISTANCE
102.3	0.0159	6.1468×10^9	9.7886465804
102.3	0.0206	3.7537×10^9	9.5744545061
102.3	0.0159	6.4534×10^9	9.8097903193
102.3	0.0159	6.4983×10^9	9.8128017178
102.3	0.0159	6.6268×10^9	9.821301957
102.3	0.0206	4.0150×10^9	9.6036813762
102.4	0.0159	6.8031×10^9	9.8327079372
102.4	0.0184	5.0943×10^9	9.7070805431
102.4	0.0159	6.8031×10^9	9.8327079372
102.4	0.0128	1.0543×10^{10}	10.0229454584
102.4	0.0159	6.8381×10^9	9.8349329654
102.4	0.0159	6.8023×10^9	9.8326561779
102.4	0.0206	4.0822×10^9	9.6108993668
102.4	0.0159	6.8356×10^9	9.8347776502
102.4	0.0159	6.8194×10^9	9.8337440125
102.4	0.0206	4.0808×10^9	9.6107437823
102.4	0.0159	6.8502×10^9	9.8357053436
102.4	0.0184	5.1295×10^9	9.7100778277
102.4	0.0159	6.8551×10^9	9.8360159555
102.4	0.0128	1.0563×10^{10}	10.0237723312
102.4	0.0159	6.8502×10^9	9.8357053436
102.4	0.0159	6.8299×10^9	9.8344154651
102.4	0.0159	6.8584×10^9	9.8362231542
102.4	0.0184	5.0687×10^9	9.7048973872

Table 1 continued

WALL PRESSURE [kPa]	WALL LEAKAGE [kg/s]	WALL FLOW RESISTANCE	LOG RESISTANCE
102.4	0.0159	6.8210×10^9	9.8338475498
102.4	0.0159	6.8937×10^9	9.8384505246
102.4	0.0128	1.0507×10^{10}	10.0214959524
102.4	0.0159	6.8904×10^9	9.8382434812
102.4	0.0159	6.8324×10^9	9.8345706501
102.4	0.0159	6.8015×10^9	9.8326044247
102.4	0.0159	6.8202×10^9	9.8337957781
102.4	0.0159	6.7869×10^9	9.8316694097
102.4	0.0128	1.0539×10^{10}	10.0227903755
102.4	0.0159	6.7869×10^9	9.8316694097
102.4	0.0128	1.0484×10^{10}	10.0205090821
102.4	0.0159	6.8064×10^9	9.8329150366
102.4	0.0159	6.8210×10^9	9.8338475498
102.4	0.0159	6.8039×10^9	9.8327597027
102.4	0.0159	6.8519×10^9	9.8358088561
102.4	0.0159	6.8202×10^9	9.8337957781
102.4	0.0159	6.8186×10^9	9.8336922532
102.4	0.0159	6.8186×10^9	9.8336922532
102.4	0.0128	1.0536×10^{10}	10.0226870178
103.0	0.0246	4.4966×10^9	9.6528828463
103.0	0.0294	3.1679×10^9	9.5007725004
103.0	0.0160	1.0890×10^{10}	10.0370080322
103.0	0.0294	3.2386×10^9	9.5103584025

Table 1 continued

WALL PRESSURE [kPa]	WALL LEAKAGE [kg/s]	WALL FLOW RESISTANCE	LOG RESISTANCE
103.0	0.0227	5.4493×10^9	9.736338421
103.0	0.0185	8.3185×10^9	9.9200476075
103.0	0.0227	5.5324×10^9	9.7429151761
103.0	0.0207	6.6750×10^9	9.8244526753
103.1	0.0279	3.7033×10^9	9.5685911352
103.1	0.0160	1.1332×10^{10}	10.0543246433
103.1	0.0207	6.7581×10^9	9.8298244102
103.1	0.0263	4.1987×10^9	9.623119829
103.1	0.0336	2.5873×10^9	9.4128458654
103.1	0.0227	5.6342×10^9	9.7508287867
103.1	0.0263	4.2267×10^9	9.6260059225
103.1	0.0207	6.7992×10^9	9.8324577926
103.1	0.0207	6.8056×10^9	9.8328695174
103.1	0.0160	1.1433×10^{10}	10.0581458901
103.1	0.0160	1.1443×10^{10}	10.0585571081
103.1	0.0246	4.8437×10^9	9.6851783568
103.1	0.0159	1.1557×10^{10}	10.0628451438
103.1	0.0279	3.7588×10^9	9.575052212
103.1	0.0207	6.7855×10^9	9.8315820476
103.1	0.0160	1.1462×10^{10}	10.0592757029
103.1	0.0185	8.5618×10^9	9.93256625
103.1	0.0160	1.1387×10^{10}	10.0563933448
103.1	0.0185	8.5527×10^9	9.9321034201
103.1	0.0227	5.6716×10^9	9.7537093472

Table 1 continued

WALL PRESSURE [kPa]	WALL LEAKAGE [kg/s]	WALL FLOW RESISTANCE	LOG RESISTANCE
103.1	0.0129	1.7658×10^{10}	10.2469404796
103.1	0.0279	3.7473×10^9	9.5737165424
103.1	0.0246	4.8214×10^9	9.6831709871
103.1	0.0361	2.2361×10^9	9.3494902801
103.1	0.0160	1.1399×10^{10}	10.0568584846
103.1	0.0160	1.1410×10^{10}	10.0572714551
103.1	0.0323	2.8037×10^9	9.4477257282
103.1	0.0129	1.7585×10^{10}	10.2451364312
103.1	0.0309	3.0499×10^9	9.4842916396
103.1	0.0159	1.1490×10^{10}	10.060325178
103.1	0.0160	1.1392×10^{10}	10.056601658
103.1	0.0185	8.5203×10^9	9.9304537301
103.1	0.0185	8.5294×10^9	9.9309187993
103.1	0.0263	4.2132×10^9	9.6246171234
103.1	0.0160	1.1380×10^{10}	10.0561364265
103.1	0.0160	1.1384×10^{10}	10.0562905591
104.0	0.0570	1.3620×10^9	9.1341756693
104.0	0.0663	1.0056×10^9	9.0024095185
104.1	0.0688	9.8456×10^8	8.9932401191
104.0	0.0548	1.4688×10^9	9.166963204
104.0	0.0622	1.1457×10^9	9.0590837057
104.0	0.0351	3.5846×10^9	9.5544448653
104.0	0.0833	6.3755×10^8	8.8045172704

Table 1 continued

WALL PRESSURE [kPa]	WALL LEAKAGE [kg/s]	WALL FLOW RESISTANCE	LOG RESISTANCE
104.0	0.0459	2.1234×10^9	9.3270367594
104.1	0.0708	9.0862×10^8	8.9583831295
104.0	0.0602	1.2213×10^9	9.0868266577
104.0	0.0440	2.3209×10^9	9.3656545309
104.0	0.0479	1.9703×10^9	9.2945374907
104.0	0.0556	1.4214×10^9	9.1527041952
104.1	0.0450	2.2746×10^9	9.3569047523
104.0	0.0718	8.4698×10^8	8.9278755155
104.0	0.0311	4.5862×10^9	9.6614555012
104.0	0.0602	1.2498×10^9	9.0968531221
104.1	0.0601	1.2555×10^9	9.098826104
104.1	0.0339	3.9809×10^9	9.5999777101
104.0	0.0724	8.4666×10^8	8.9277093142
104.0	0.0460	2.1296×10^9	9.3282969389
104.0	0.0615	1.1918×10^9	9.0761952449
104.1	0.0585	1.3328×10^9	9.1247698405
104.1	0.0702	9.2228×10^8	8.9648614352
104.0	0.0450	2.2213×10^9	9.3466071306
104.1	0.0478	1.9976×10^9	9.3005184743
103.9	0.0399	2.7212×10^9	9.4347540776
104.1	0.0675	1.0003×10^9	9.0001259417
104.0	0.0264	6.3399×10^9	9.8020795846
104.0	0.0469	2.0739×10^9	9.3167893577

Table 1 continued

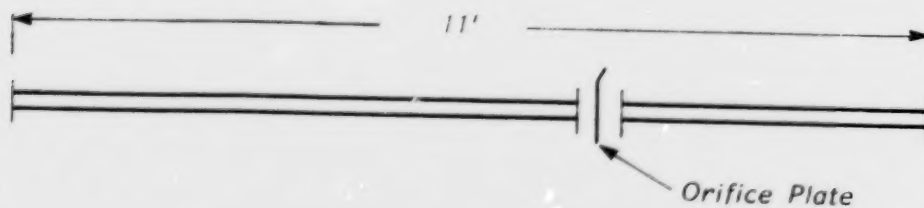
WALL PRESSURE [kPa]	WALL LEAKAGE [kg/s]	WALL FLOW RESISTANCE	LOG RESISTANCE
104.1	0.0338	3.9870×10^9	9.6006469467
104.1	0.0504	1.7886×10^9	9.2525150677
104.1	0.0676	9.9823×10^8	8.9992292622
103.9	0.0628	1.0943×10^9	9.0391198031
104.0	0.0675	9.6127×10^8	8.9828469521
104.0	0.0743	8.0485×10^8	8.9057126831
103.9	0.0663	9.8123×10^8	8.9917698827
104.0	0.0338	3.9165×10^9	9.5928996003
103.9	0.0430	2.3255×10^9	9.3665079284
104.0	0.0629	1.1439×10^9	9.0583707139
104.0	0.0281	5.6101×10^9	9.7489679401
104.0	0.0281	5.5309×10^9	9.7427965331
104.0	0.0663	1.0112×10^9	9.0048218045
105.1	0.2564	9.5241×10^7	7.9788230322
104.8	0.2868	7.0650×10^7	7.849110371
104.9	0.3240	5.7342×10^7	7.7584741293
105.1	0.3442	5.3248×10^7	7.7262997536
105.0	0.3279	5.7358×10^7	7.7585922109
104.7	0.3085	5.9420×10^7	7.7739321214
104.5	0.3226	5.0200×10^7	7.7007006337
104.5	0.2889	6.2432×10^7	7.7954100658
104.4	0.3043	5.5100×10^7	7.7411521296
104.7	0.3124	5.8058×10^7	7.7638609707

Table 1 continued

WALL PRESSURE [kPa]	WALL LEAKAGE [kg/s]	WALL FLOW RESISTANCE	LOG RESISTANCE
104.8	0.2923	6.6769×10^7	7.8245735231
104.4	0.3116	5.1909×10^7	7.7152390384
104.6	0.3212	5.2157×10^7	7.7173112905
104.5	0.3259	4.9436×10^7	7.6940404337
104.4	0.3257	4.8530×10^7	7.6860147328
104.6	0.3064	5.7298×10^7	7.7531431176
104.4	0.3248	4.7876×10^7	7.680120627
104.4	0.3215	4.8880×10^7	7.6891286423
104.7	0.3059	6.0116×10^7	7.7789906014
104.4	0.3139	5.1135×10^7	7.7087216787
104.4	0.3163	5.0888×10^7	7.7066122308
104.3	0.3146	5.0419×10^7	7.7025937941
104.7	0.3191	5.5007×10^7	7.7404217275
104.7	0.3153	5.6751×10^7	7.7539704614
104.7	0.3364	4.9481×10^7	7.6944428178
104.3	0.3263	4.6269×10^7	7.6652864029
104.7	0.3203	5.5486×10^7	7.7441870541
104.8	0.3389	5.0250×10^7	7.7011380834
104.6	0.3637	4.1696×10^7	7.6200907019
104.7	0.3982	3.5350×10^7	7.5483833877
104.9	0.4412	3.0749×10^7	7.4878306636
104.9	0.4439	3.0302×10^7	7.4814750804
104.9	0.4454	2.9760×10^7	7.4736355318

Table 1 continued

WALL PRESSURE [kPa]	WALL LEAKAGE [kg/s]	WALL FLOW RESISTANCE	LOG RESISTANCE
104.9	0.4698	2.6619×10^7	7.4251861531
104.8	0.4469	2.9238×10^7	7.4659507491
104.8	0.4401	2.9699×10^7	7.4727409751
104.8	0.4481	2.8523×10^7	7.4551985662
104.8	0.4474	2.8505×10^7	7.4549150533
104.9	0.4711	2.6447×10^7	7.422376525
AVERAGE FLOW RESISTANCES			
6.9218×10^9	7.6565×10^9	2.0298×10^9	4.8836×10^7
AVERAGE FLOW RATES [kg/s]			
0.0161	0.0216	0.0540	0.3494
PRESSURE RANGES [kPa]			
102.4	103.1	104.0	104.8



Above Sections Assembled on Site

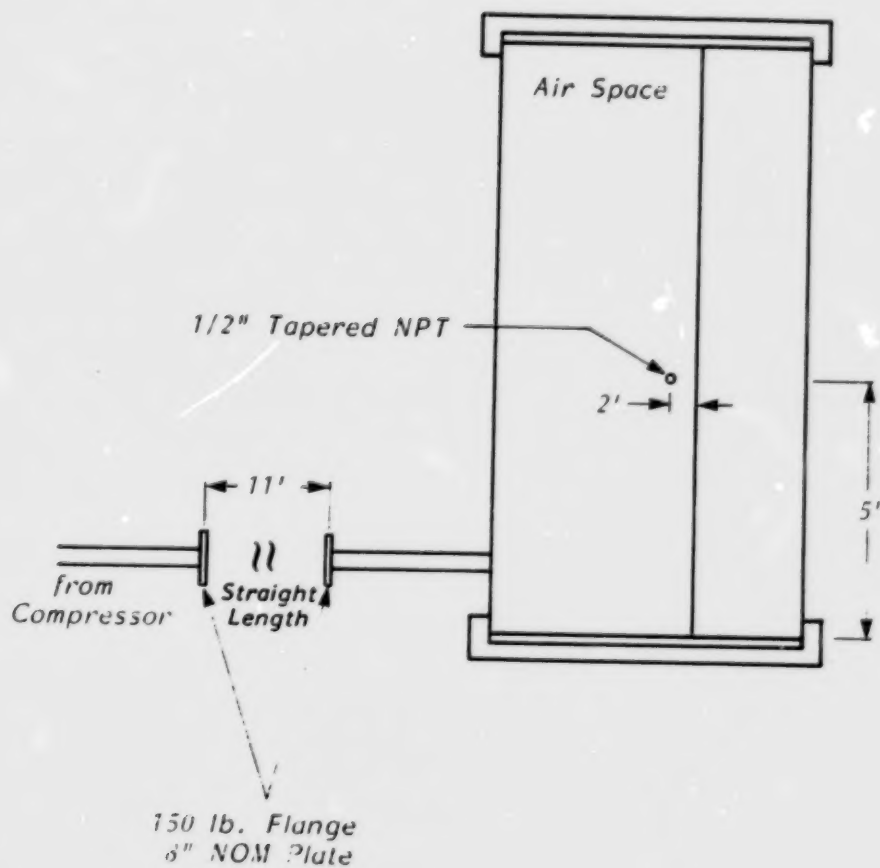


FIGURE 1
PROVISION FOR INSTRUMENTATION



Figure 2: Block Wall and Frame



Figure 3: Air Compressors

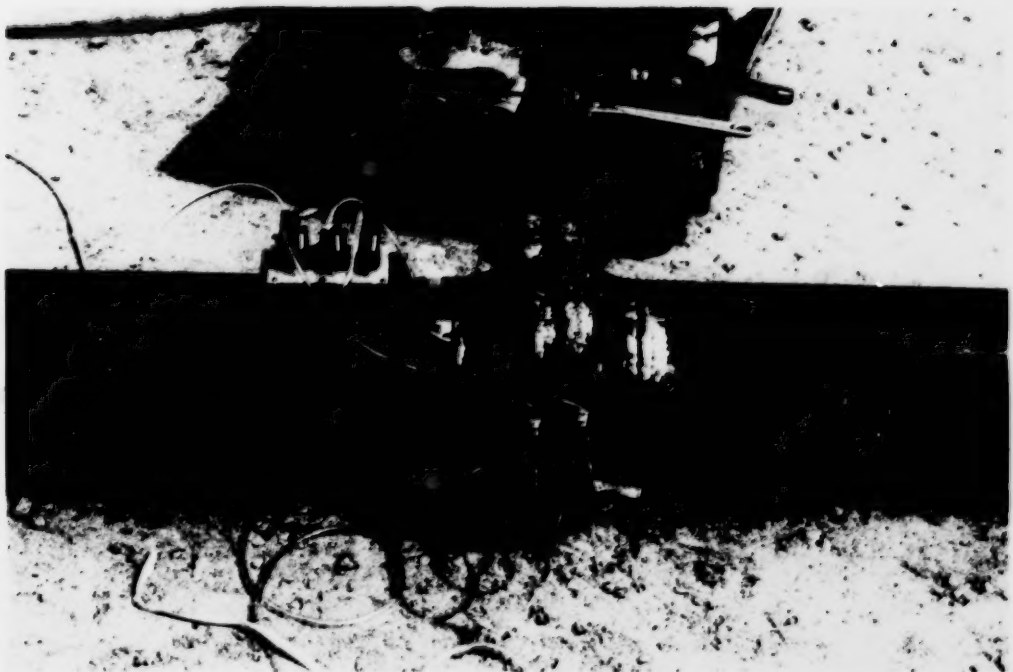


Figure 4: Orifice Plate & Pressure Transducers

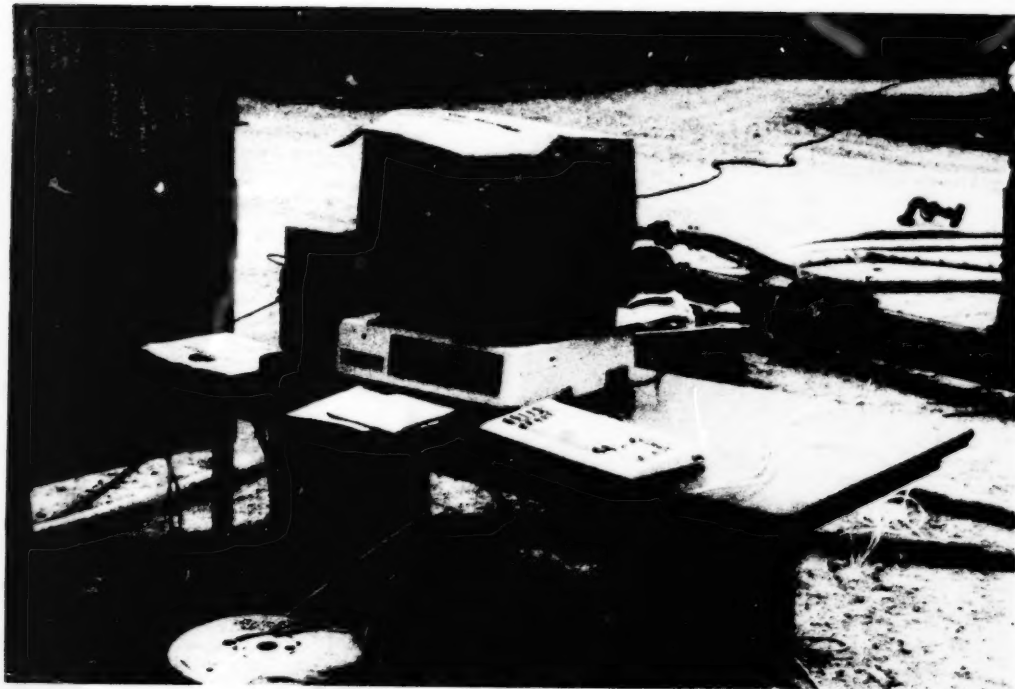


Figure 5: Data Acquisition Equipment

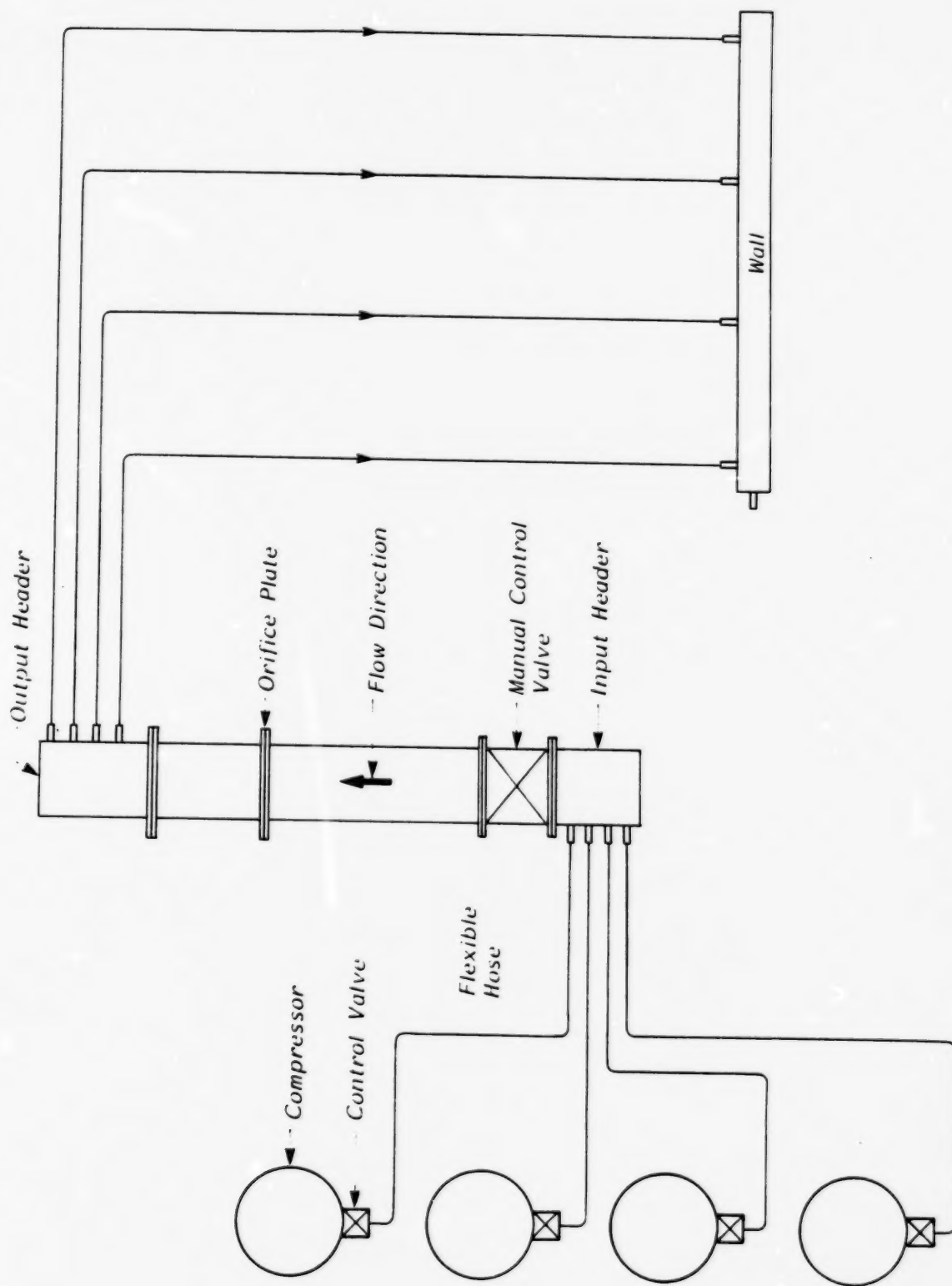


FIGURE 6
SCHEMATIC OF AIR CIRCUIT



Figure 7: Orifice Spool Piece



Figure 8: Block Wall Enclosure

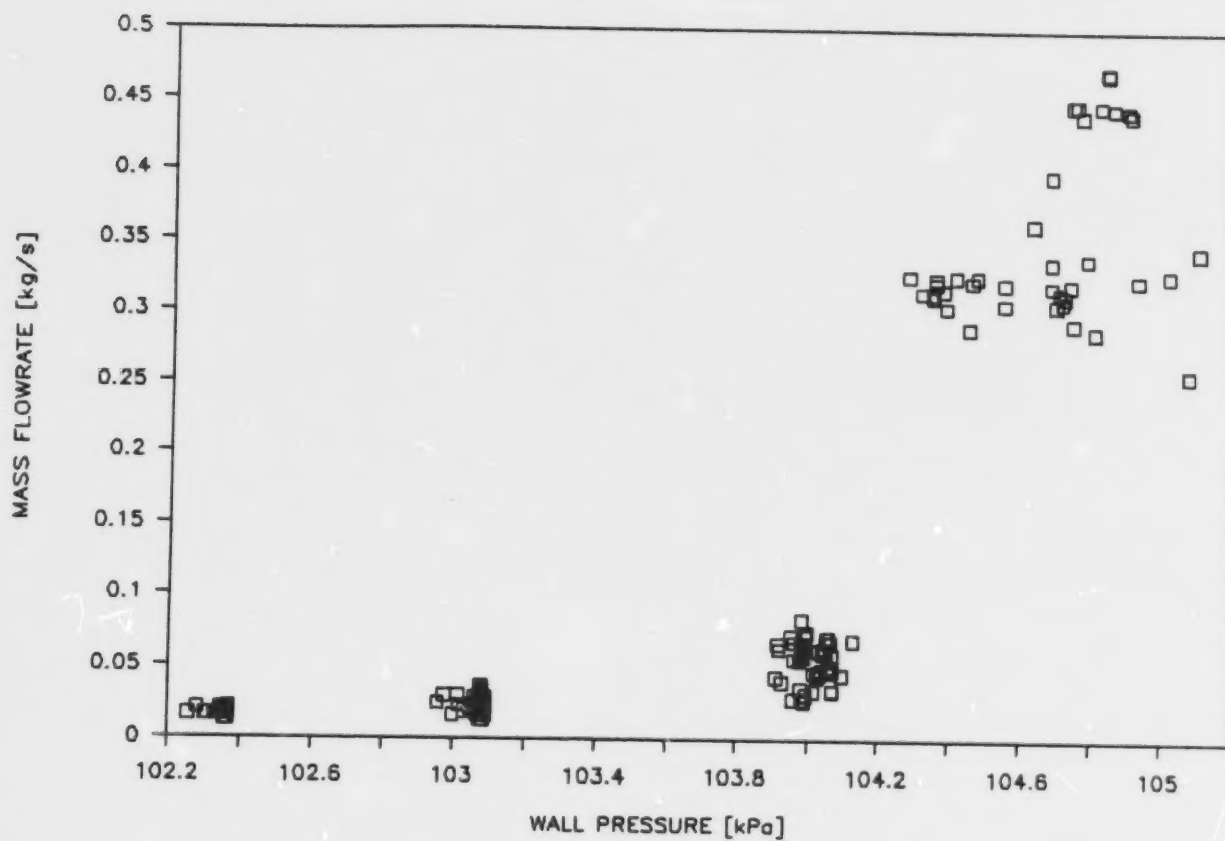
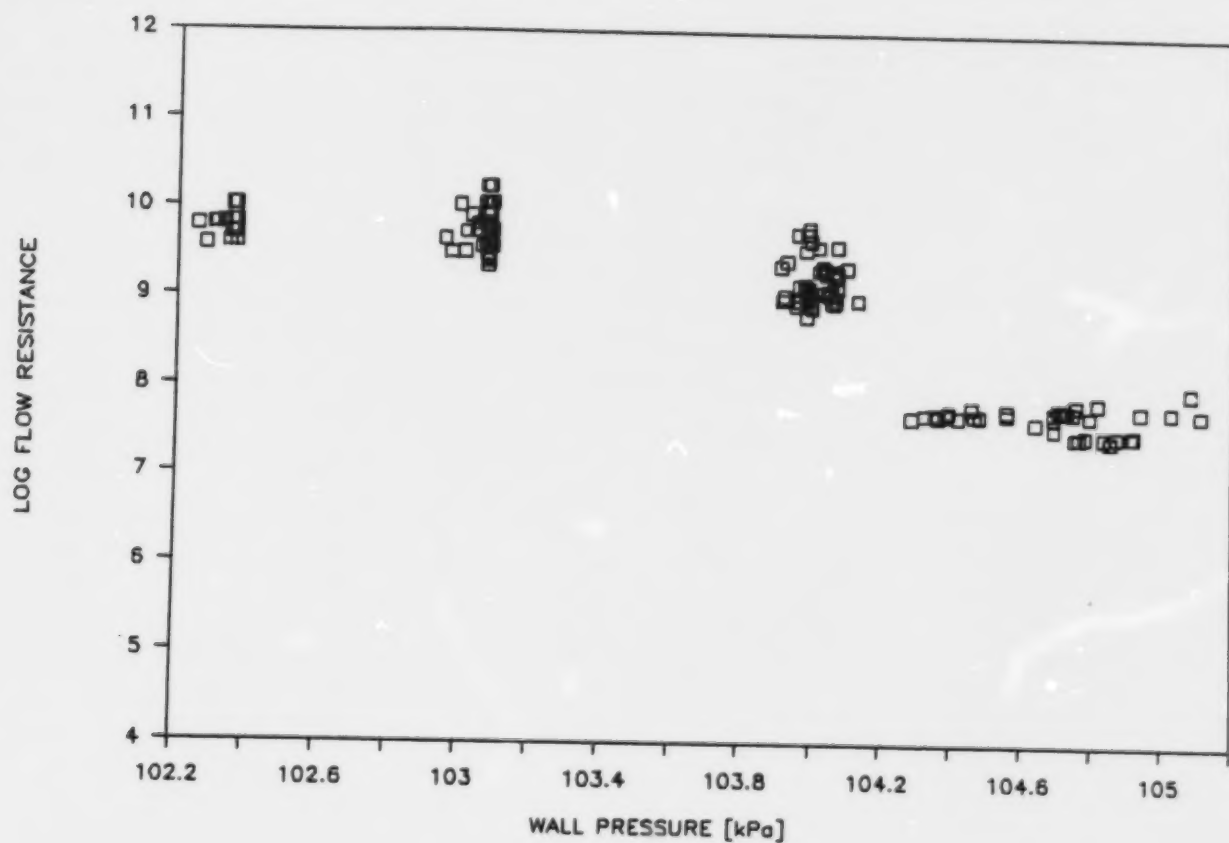


FIGURE 9
WALL LEAKAGE



Figure 10: Block Wall After Enclosure Pressure of 0.5 psig



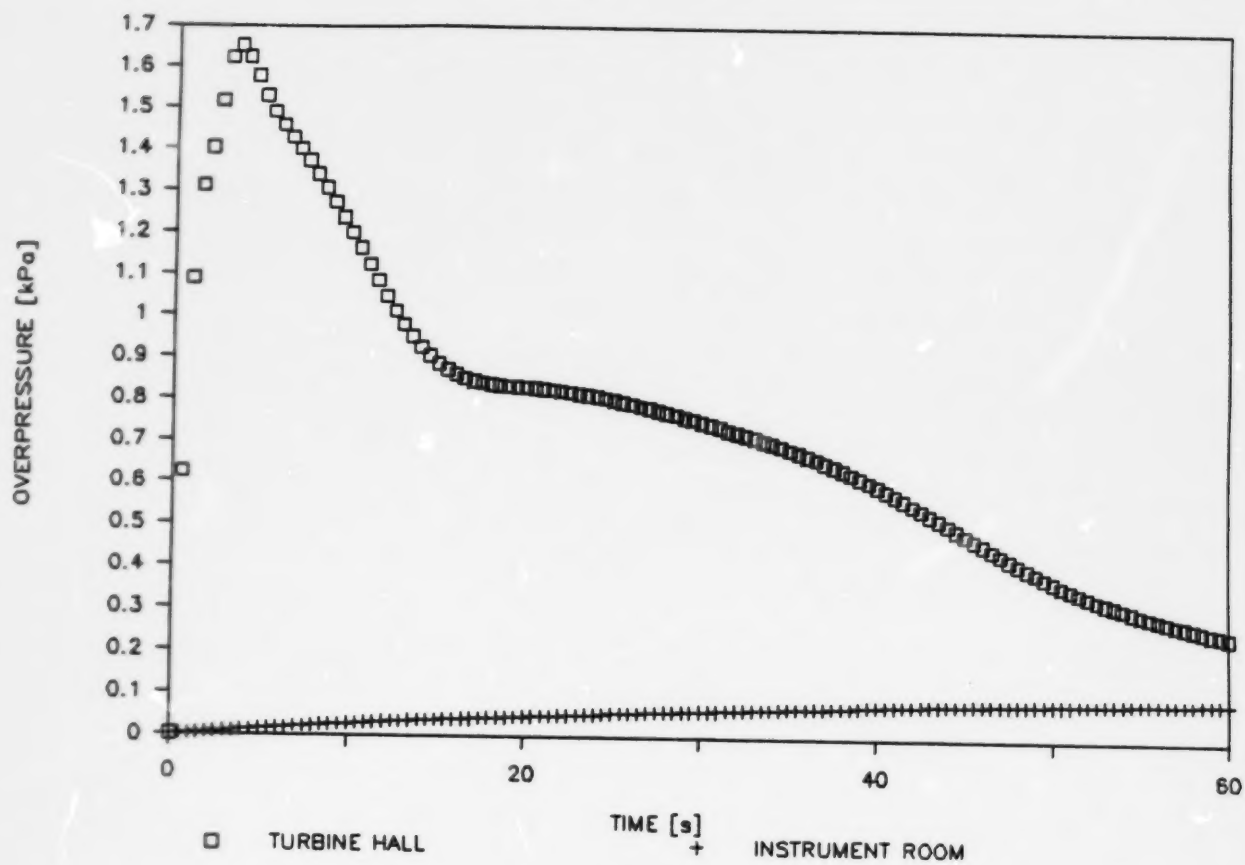


FIGURE 12
PRESSURE PROFILE 100% SM, KI=7.3E+09

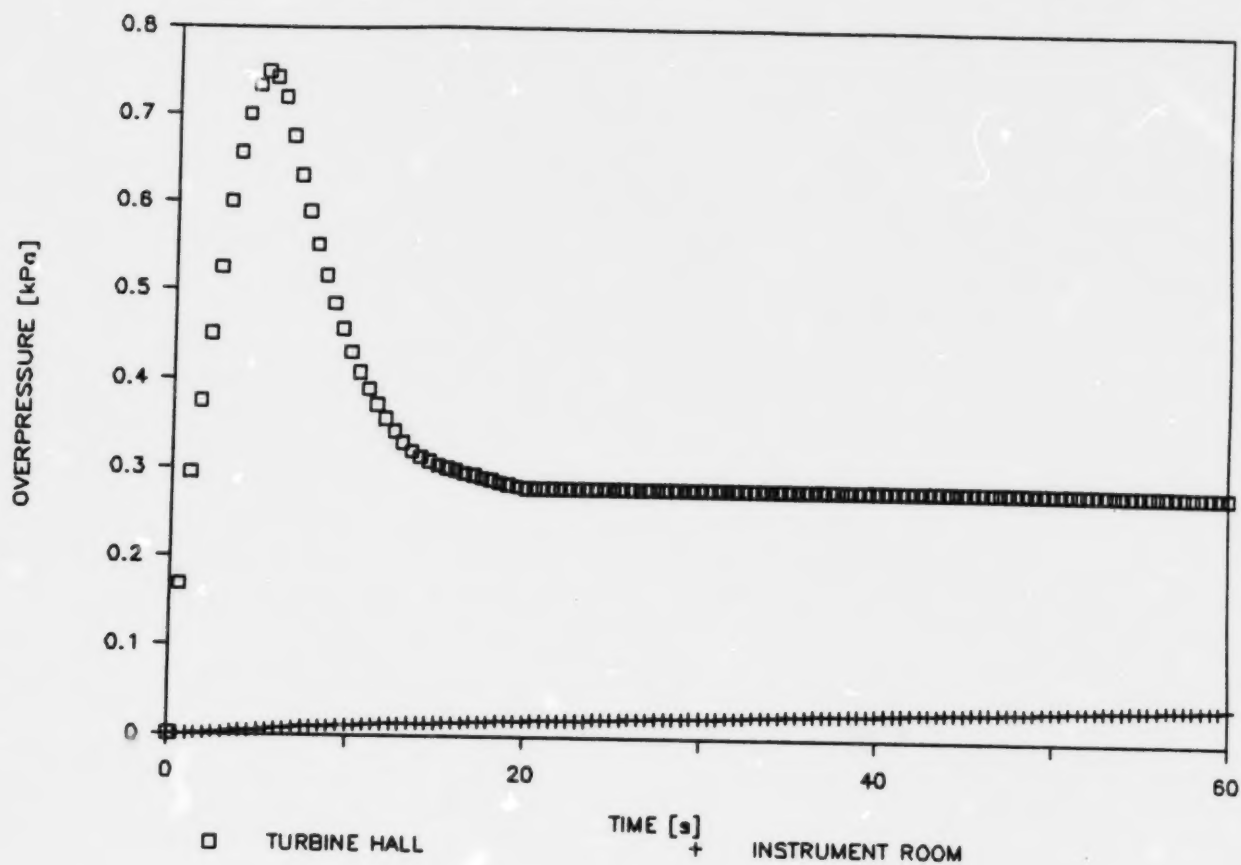


FIGURE 13
PRESSURE PROFILE 20% SM, $KI=7.3E+09$

APPENDIX A

Estimate of Flow Resistance Through a Block Wall

Problem: Calculate the flow resistance through a block wall given the pressure decay times and the initial pressures.

Solution: Model the block wall as a pipe with a flow restriction. The upstream end of the pipe is connected to a reservoir with an initial pressure P_0 . The downstream end of the pipe is open to atmosphere.

Perform a mass balance on the pipe and reservoir:

change in mass within the reservoir -
mass flowrate through the pipe

$$\text{or } \frac{dM}{dt} = \dot{m}$$

assume an ideal gas

$$M = \frac{PV}{RT} \quad \text{LHS} = \frac{V}{RT} \frac{dP}{dt}$$

assume the process is isothermal

pipe friction equation for isothermal compressible flow

$$P^2 - P_a^2 = \frac{\dot{m}^2 RT}{A^2} 2 \ln \frac{P}{P_a} + f_d \frac{1}{d} \quad /1/$$

replace the pipe friction factor with a loss coefficient

$$P^2 - P_a^2 = \frac{\dot{m}^2 RT}{A^2} 2 \ln \frac{P}{P_a} + K \frac{1}{L}$$

assume $P \approx P_a$, then the RHS is expressed as

$$\dot{m} = \frac{A}{\sqrt{RTK_L}} \sqrt{P^2 - P_a^2}$$

equate LHS & RHS

$$\frac{V}{A} \sqrt{\frac{K_L}{RT}} \frac{dP}{\sqrt{P^2 - P_a^2}} = - dt$$

$$\text{let } x = P/P_a \quad dx = dP/P_a$$

$$\frac{V}{A} \sqrt{\frac{K_L}{RT}} \frac{dx}{\sqrt{x^2 - 1}} = - dt$$

$$\begin{aligned} \text{where } x &= P_o/P_a \text{ when } t = 0 \\ x &= 1 \text{ when } t = t_o \end{aligned}$$

$$\text{given } \frac{dx}{\sqrt{x^2 - a^2}} = \ln(x + \sqrt{x^2 - a^2}) \quad /2/$$

integrating and rearranging

$$K_L = \frac{A^2}{V^2} RT t_o^2 \frac{1}{\ln[P_o/P_a + \sqrt{(P_o/P_a)^2 - 1}]}$$

Volume of Air Space

$$V = 10' \times 10' \times 7.5" = 62.5 \text{ ft}^3 = 1.77 \text{ m}^3$$

Area of the Wall

$$A = 10' \times 10' = 100 \text{ ft}^2 = 9.29 \text{ m}^2$$

Temperature of Air $T = 25^\circ\text{C}$ or 300K

Gas Constant (air) $R = 286 \text{ J/(kg K)}$

Po [psig]	t _o [sec]	K _L
0.5	5	227x10 ⁶
1.0	7	316x10 ⁶
1.15	8	385x10 ⁶
1.25	8	369x10 ⁶
1.5	9	427x10 ⁶
1.75	10	489x10 ⁶
2.0	10	458x10 ⁶
2.25	10	433x10 ⁶
2.5	10	411x10 ⁶
2.75	11	475x10 ⁶
3.0	12	542x10 ⁶
3.5	13	590x10 ⁶
4.0	13	593x10 ⁶

References

1. J.K. Vennard, R.L. Street, Elementary Fluid Mechanics, John Wiley & Sons, Toronto, 1976.
2. CRC Math Tables, 4th edition.

APPENDIX B

Data Reduction

Calculate the mass flowrate of air through an orifice given the pressure measurements at the flange taps.

P_1 - gauge pressure at the upstream flange tap [psig]

P - the pressure drop across the two flange taps [psi]

the ideal flowrate for a gas passing through an abrupt contraction assuming the process is isentropic is given by:

$$\dot{m}_{ideal} = \frac{A_2(P_1 + 14.7)}{\sqrt{RT/gc}} \left[\frac{(2\gamma)}{(\gamma-1)} \frac{(r^{2/\gamma} - r^{(\gamma+1)/\gamma\beta^4})}{(1-r^{2/\gamma\beta^4})^2} \right]^{1/2}$$

where

r - ratio of absolute pressures across the orifice
- $(P_1 + 14.7 - P)/(P_1 + 14.7)$

T - temperature of the air at the orifice plate [$^{\circ}R$]
- $560^{\circ}R$ ($100^{\circ}F$)

D - the diameter of the pipe = 7.981"

d - the diameter of the orifice = 2.4053"

β - the diameter ratio d/D = 0.3014

A_2 - the area of the orifice = 4.5439 in²

γ - the ratio of specific heats for air = 1.4

R - the ideal gas constant for air = 53.34 lbf-ft/lbm-R

gc = 32.1739 ft-lbm/lbf-s²

the actual mass flowrate can be calculated from the orifice discharge coefficient which is defined as:

$$C_{DS} = \dot{m}_{actual} / \dot{m}_{ideal} \quad (2)$$

for the range of flowrates given in this application, the orifice discharge coefficient is best calculated from the Stoltz equation for a flange tap orifice/1/:

$$C_{DS} = 0.5959 + 0.0312 \beta^{2.1} - 0.184 \beta^8$$

$$+ 0.0029 \beta^{2.5} (10^6 / (Rd \beta))^{0.75}$$

$$+ 0.09(1/D) \beta^4 / (1 - \beta^4) - 0.0337(1/D) \beta^3 \quad (3)$$

where $Rd = 48 \dot{m}_{actual} / (\pi d \mu)$

(4)

and μ = the viscosity of air at 100°F

$$= 0.1237 \times 10^{-4} \text{ lbm/ft-s}$$

The calculation procedure is as follows:

1. Calculate $\dot{m}_{ideal}$ from eqn. (1)
2. Calculate the initial discharge coefficient from eqn. (3) estimating an initial value for Rd
3. Calculate $\dot{m}_{actual}$ from eqn. (2)
4. Calculate the new Rd from eqn. (4)
5. Calculate the new C_{DS} from eqn. (3)
6. Calculate the new $\dot{m}_{actual}$ from eqn. (2)
7. Repeat steps 4-6 until $\dot{m}_{actual}$ converges

Calculate the wall flow resistance given the air mass flowrate through the wall, $\dot{m}_{actual}$, and the wall pressure, P_w . The equation for isothermal compressible flow through a pipe, as applied in Appendix A is used:

$$K_L = \frac{A^2 g_c}{RT \dot{m}^2} ((P_w + 14.7)^2 - 14.7^2)$$

where K_L = the wall flow resistance

A = the area of the wall [in^2]

P_w = the pressure at the wall [psig]

References

1. R.P. Benedict, Fundamentals of Temperature, Pressure and Flow Measurements, John Wiley & Sons, Toronto, 1984.

APPENDIX C

Pressure History Simulation

Model the wall as a pipe with a flow restriction. The turbine hall and instrument room are modelled as reservoirs connected to either end of the pipe. The equation describing the pressure across the pipe is:

$$P^2 - P_c^2 = \frac{\dot{m}^2 RT}{A^2} \left(2 \ln \frac{P}{P_c} + K_L \right) \quad (1)$$

Since the flow loss is much greater than the logarithmic term, the equation can be simplified to:

$$P^2 - P_c^2 = \frac{\dot{m}^2 RT}{A^2} + K_L \quad (2)$$

mass balance of the instrument room

mass entering instrument room = mass increase in instrument room

LHS = $\dot{m}$ defined by eqn. 2

$$\text{RHS} = \frac{dM}{dt} = \frac{V}{RT} \frac{dP}{dt} \quad (3)$$

combine eqns. 2 & 3 and rearrange

$$dt = \frac{V}{A} \sqrt{\frac{K_L}{RT}} \frac{dP_c}{\sqrt{P^2 - P_c^2}}$$

expressed differentials as a finite difference

$$\Delta t = C \frac{\Delta P_c}{\sqrt{P^2 - P_c^2}}$$

using the implicit solution, the recursive equation is:

$$t_{N+1} - t_N = C \frac{P_c(t_{N+1}) - P_c(t_N)}{\sqrt{P^2(t_{N+1}) - P_c^2(t_{N+1})}}$$

where $C = \frac{V}{A} \sqrt{\frac{K_L}{RT}}$

the solution algorithm is as follows:

1. let $P_c(t_n) = P_c(t_{n-1})$
2. $P_c'(t_n) = \Delta t / C \sqrt{(P^2(t_n) - P_c^2(t_n))} + P_c(t_{n-1})$
3. if $P_c'(t_n) - P_c(t_n) > \epsilon$ go to 1
4. go to next time step